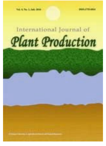

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Physio-agronomic performance of spring cultivars *T. aestivum* and *T. spelta* grown in organic farming system

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Abstract

One of the goals of organic crop production is to grow species which combine traditional pro-healthy properties, innovative cultivation practices and harmony with the environment. Among the ancient species the spring spelt is especially predisposed for organic farming. In comparison with common wheat spring spelt has a relatively short research history on physiological analysis of growth and development. The objective of this study has been to compare the agronomic performance and growth characteristics of spring varieties of *Triticum spelta* L. and *Triticum aestivum* L. cultivated in the organic farming system and sown on different dates. The basis for the research were data from field plot experiments arranged in completely randomized blocks carried out in 2010 and 2011. The factors were cultivars: two cultivars of *T. aestivum* (Trappe, Waluta) and two cultivars of *T. spelta* (Roter Sommerkolben, Speltz aus Tzaribrod) and sowing terms: optimal and postponed by two weeks. During the seasons there were assessed: weed infestation and disease resistance, leaf chlorophyll index, biometric measurements associated with plant morphology and yielding and nutritional value of grains. It was stated that cultivars of *T. spelta* are more tolerant to unfavorable environmental conditions than cultivars of *T. aestivum*, showing better adaptability to habitat conditions, when-due to the worse weather-the uptake of nutrients from soil can be limited, stronger competitiveness against weeds and higher tolerance to diseases of leaves and stems. The content of chlorophyll in spelt wheat grown in organic cultivation as well as yields are very stable across years. Under unfavourable weather conditions during the season, spelt wheat can give yields which compare to yields of common wheat, but when in the favorable weather conditions common wheat varieties generate yields higher by 42% (cv. Trappe) up to 47% (cv. Waluta).

Keywords: Chlorophyll content; Grain quality; Organic farming; *Triticum aestivum* L.; *Triticum spelta* L.; Yielding.

Abbreviations

Y: Year
V: Variety/Cultivar
T: cv. Trappe
W: cv. Waluta
R: cv. Roter Sommerkolben
S: cv. Spletz aus Tzaribrod
ST: Sowing Time
LS: Length Stem (cm)
SL: Spike Length (cm)
KS: Kernels per Spike (no)
KWS: Kernel Weight per Spike (g)
TKW: Thousand Kernel Weight (g)
GY: Grain Yield (kg ha^{-1})
SY: Straw Yield (kg ha^{-1})
HI: Harvest Index (%)
GS: Growth Stage (Zadoks et al., 1974)
SPAD: Soil Plant Analysis and Development (units)

Introduction

The development of organic farming, which responds to the consumer's demand for organic products and to lifestyle changes, engages farmers in protection of the environment. Predictably, eco-products will become the most profitable domestic exports of agricultural products in Canada, the United States, Australia and the EU countries (Ortiz Escobar and Hue, 2007; Lacko-Bartosova et al., 2010). The annual growth rate of the area under organic production has increased by 20% in the last decade (Lotter, 2003). Globally, organic agriculture covers over 31 million ha, while in Europe it encompasses 6.9 million ha (27% production of the world), including 0.9 million ha in Poland (Ortiz Escobar and Hue, 2007). According to the Organic Trade Association, in the US alone the organic food market rose from 3.5 billion dollars in 1996 to 28.6 billion dollars in 2010 (Forman and Silverstein, 2012).

The philosophy of crop production in the organic agriculture system is to grow species which combine tradition, innovation and harmony with the environment. Another focus is to obtain high health benefits from food. Other distinguishing features of organic farming include reduced soil requirements and increased tolerance to unfavorable temperature and water conditions (Ehsanzadeh, 1998; Schmid et al., 2001). Even if yields of organic crops are lower, this system plays an important role in the development of agriculture (Murphy et al., 2007; Wolfe et al., 2008). The progress is mainly achieved in the breeding of new varieties and improved knowledge of biological processes when adopted in organic farming (Konvalina et al., 2014). The European breeding program concentrates mostly on *Triticum*, as this is the most important genus among organic cereals (Wolfe et al., 2008). New varieties of *Triticum* are adaptable to environments with low N availability (Heyden, 2004). Besides, new varieties are better at using nitrogen and other nutrients, adapting to soil microbes, competing with weeds and resisting insects or diseases (Murphy et al., 2007; Wolfe et al., 2008).

In organic production of cereals, the leaf chlorophyll (Chl) content is one of the most important traits from the eco-physiological point of view and crop management. For example, this trait may be taken advantage of in precision agriculture. The leaf pigment concentration affects the rate of photosynthesis, e.g. low concentrations of chlorophyll can inhibit directly this process, reducing yields (Curran et al., 1990; Filella et al., 1995; Zuk-Golaszewska, 2008). Greenness of leaves can be related to the plant stress physiology and is a significant trait in the breeding of new lines of wheat (Lopes et al., 2012). Generally, the higher the chlorophyll content, the lower the environmental stresses. Leaf nitrogen is incorporated in the chlorophyll content, which gives an indirect measure of the nutritional status of plants (Moran et al., 2000). In the organic farming system, nutrient management is often based on the knowledge of soil fertility, mainly nitrogen (N) fixation and nutrient recycling from organic materials, such as farmyard manure and crop residues, with limited inputs from permitted fertilizers (Gosling and Shepherd, 2005). The N synchronization between the N release from manures and N demand by crops could minimize or even eliminate the N deficiency problem (Myers et al., 1997; Hue and Silva, 2000). This could be achieved by a non-invasive method of the determination of chlorophyll with an SPAD-502 device. This is a way to assess the nitrogen supply of plants so as to decide whether additional N fertilization is needed (Peltonen et al., 1995). The authors developed critical and optimal intervals for the SPAD chlorophyll content of wheat during the shooting and heading stages.

Several old plant species (varieties) have been reintroduced into organic breeding and farming (Lang, 2006). An example of a re-discovered plant is spelt, an old, not free threshing wheat species. Some other medicinal plants are next in line among ancient species awaiting to be used old as future healthy food. There are both spring and winter spelt varieties, with winter ones more popular among organic farmers (Lacko-Bartosova et al., 2010). *Triticum spelta* is an essential element of functional food because of its high nutritional value. One of the basic parameters of the technological quality of *Triticum* is wet gluten. Genetically pure varieties of *T. spelta* are characterized by lower yields, a high content of lower quality wet gluten and higher concentrations of macro- and micronutrients (Lacko-Bartosova et al., 2010). Besides, *T. spelta* is less demanding than *T. aestivum*. With respect to soil. Being more resistant to adverse weather conditions and environmental stresses such as low temperatures and water deficit, *T. spelta* can grow in different locations and on different soils and adapt itself to both cool and wet conditions (Lacko-Bartosova et al., 2010). Moreover, spelt plants compete well with weeds and remain wholesome. The spelt kernel is tightly enclosed in a hull, which is a natural barrier against diseases (Kema and Lange, 1992; Wiwart et al., 2004).

Spelt has a very short research history compared to common wheat, so there is significant potential for obtaining better yields by simple breeding selection and a crop technology adequate to the plant's agronomic characteristics. Besides, too little is known about the growth and development of spring spelt. The objective of this study has been to compare the agronomic performance and growth characteristics of spring varieties of *T. spelta* and *T. aestivum* cultivated in the organic farming system and sown on different dates.

Material and Methods

In 2010 and 2011, field trials were carried out in north-eastern Poland (latitude N 53° 42' N, longitude 20° 26' W). This region is exposed to the continental agricultural climate, with cold winters and relatively hotter and drier summers. The lowest mean daily air temperature is -26.5 °C, while the highest reaches 30.3 °C. The coldest months are December, January and February. The summer (June, July and August) is characterized by an average maximum temperature of 22.0 °C. The annual precipitation is approximately 600 mm a year (Szwejkowski, 2011).

The factors in the field plot experiment were two spring varieties of common wheat (*Triticum aestivum* L.) Trappe, Waluta and two spring varieties of spelt wheat (*Triticum spelta* L.) Roter Sommerkolben, Spletz aus Tzaribrod (Table 1.); the other set of factors was composed of two sowing terms: first date (optimal) on 14 April (2010) and 12 April (2011) and the second one postponed in each year by 14 days.

Table 1. Characteristics of the analyzed cultivars of *Triticum aestivum* L. and *Triticum spelta* L.

T. aestivum L., cv. Trappe: A bread cultivar of spring common wheat. It grows to the height of 89 cm; relatively resistant to lodging. On a nine-point scale of plant infestation (9-plants with no symptoms, it scores: 8.1 diseases of the stem base, 8.3 powdery mildew, 7.7 brown rust, 6.9 yellow rust, 7.6 brown leaf blight, 7.1 spetoria leaf spot, 7.4 spetoria glume blotch and 7.4 head blight. The thousand grains weight 35.7g, seed levelling 64%. It yields at around 61.4 dt ha^{-1} provided a high level of agronomic technology (Descriptive List of Agricultural Plant Varieties 2011).
T. aestivum L., cv. Waluta: an intensive cultivar of spring common wheat, quality wheat (group A). The average plant height 99 cm. The scores for the plant infestation index: 8.0 diseases of the stem base, 7.3 powdery mildew, 7.2 brown rust, 9.0 yellow rust, 7.4 brown leaf blight, 6.8 spetoria leaf spot, 7.4 spetoria glume blotch and 7.6 head blight. The thousand grains weight 35.7g, seed levelling 64%. It yields at around 58.3 dt ha^{-1} provided a moderate level of agronomic technology (Descriptive List of Agricultural Plant Varieties 2011).
T. spelta L., cv. Speltz aus Tzaribrod: a spring cultivar of spelt, unthreshable. The average number of grains per head 17. The weight of grains from a head in controlled field experiments 0.40 g, the thousand grains weight 23.9g. Quite vulnerable to fungal diseases. The DON level in grains after the inoculation of plants with *Fusarium culmorum* was 105.0 µg g^{-1} (Wiwart et al., 2004).
T. spelta L., cv. Roter Sommerkolben: a spring cultivar of spelt, unthreshable. The average number of grains per head 15.05. The weight of grains from a head in controlled field experiments 0.40 g, the thousand grains weight 24.4 g. Very health plants. The DON level in grains after the inoculation of plants with *Fusarium culmorum* was 36.9 µg g^{-1} (Wiwart et al., 2004).

The wheat varieties were cultivated in the organic farming system without fertilization. The preceding plant was potato fertilized with on 30 t ha^{-1} of manure. The soil cultivation was traditional. In the autumn, after harvesting the preceding crop, disk harrowing followed by ploughing were carried out. In the early spring, in order to smooth the soil surface, it was cultivated and harrowed. Before sowing, the field was harrowed again to weed control. In Poland, the Act of 25 June 2009 regulates organic farming (Journal of Law No 116, item 975).

In each year, the experiment was established in a randomized complete block design in four replications and located on soils of very good rye complex. The soils were characterized by pH 5.3, relatively high content of P (98 mg kg^{-1} soil) and medium content of K (162.5 mg kg^{-1} soil) and Mg (60.9 mg kg^{-1} soil). The kernels of the common wheat varieties were sown in rows spaced at 20 cm, at the depth of 3 cm. The spelt varieties were sown as spikeletes (two kernels) at the depth of 5 cm. A single experimental plot was 2.4 m × 4.0 m = 9.6 m^2.

Weed control and disease resistance

During the vegetative season, the infestation by weeds and diseases was observed. The observations were performed at the tillering stage and before harvest. The composition and abundance of weed species were estimated on the basis of a sampling area of 0.25 m^2 and recalculated to an area of 1 m^2. The health of leaves were assessed at GS 73 and spikes at GS 75 (Zadoks et al., 1974). The percentage area of leaves and spikes infested by fungal pathogens was assessed against the EPPO Standards (1999). The root rot disease was determined at GS 89 with the use of a two-step scale (Mackiewicz and Drath, 1972) and the results were given as the injury index (%) (Townsend and Heuberger, 1943).

Leaf chlorophyll index

The chlorophyll content in leaves was measured at the following stages GS 17, GS 25, GS 35 and GS 42. It was assumed that a given development phase had been reached when at least 60% of the plants in the canopy were in that phase (Waddington et al., 1983). The leaf chlorophyll concentration was estimated with a SPAD 502 chlorophyll meter, Minolta, Japan. Measurements were made at the middle part of each leaf. The average of five readings was taken as an SPAD value.

Biometrics measurements

The plant height (stem length, spike length), yield components (number of kernels per spike, thousand kernels weight) and yielding (hulled grain and straw) were measured. Finally, the harvest index as the ratio between grain yield and straw yield was calculated.

Nutritional value

For qualitative analyses, total ash and the content of macronutrients (N, Ca, P, Mg, Na, K) and micronutrients (Cu, Fe, Mn, Zn) were determined at the full maturity of kernels. In order to determine the amount of macronutrients and mineralized material, kernels were ground in concentrated sulfuric acid with hydrogen dioxide added as an the oxidant. The nitrogen content was determined colorimetrically using the hypochlorite colorimetric method; the phosphorus content was assessed by the vanadium-molybdenum method, while the concentrations of potassium and calcium were assayed with the photo-flame Atomic Emission Spectroscopy (AES) method. The concentrations of iron, magnesium, copper, zinc and manganese were measured by atomic absorption spectrometry on a Shimadzu Atomic Absorption Spectrophotometer (1999).

Statistical analysis

All statistical calculations were performed using a STATISTICA® package. In order to evaluate and compare treatment means, the Tukey's T test was applied, setting the Tukey's HSD (Honest Significant Difference) at the significance level P<0.05.

Results and Discussion

Weather conditions in the vegetative season

The temperatures and precipitations during the growing season in the two-year experiment were above averages from 40-year-long records (1966-2005). In general, the weather conditions were unfavorable for exploiting the wheat yielding biological potential. Regarding the two years of our experiment, it appears that the meteorological conditions in the growing season of 2011 were more propitious for the plant growth and development than in 2010.

Table 2. Meteorogical data for 2010 and 2011 according to the Meteorogical Station in Tomaszkowo, Poland.

Month	Temperature (°C)			Precipitation (mm)		
	2010	2011	1966-2005[1]	2010	2011	1966-2005[1]
January	-9.0	-1.5	-3.3	19.4	34.8	33.2
February	-3.0	-5.8	-2.3	22.5	36.9	26.6
March	2.1	1.6	1.4	36.7	16.3	33.3
April	8.1	9.1	6.8	18.2	22.5	38.6
May	12.0	13.1	12.8	131.9	51.5	54.0
June	16.4	17.1	15.7	84.8	81.7	74.7
July	21.1	17.9	17.5	80.4	202.8	76.9
August	19.1	17.6	17.0	95.3	82.1	66.2
September	12.0	14.1	12.5	40.5	67.5	56.8
October	5.0	8.3	7.7	24.1	29.5	51.1
November	4.4	3.1	2.4	121.4	14.1	46.3
December	-6.8	2.3	-1.4	57.2	25.8	42.3

[1] Data from the period 1966-2005.

In 2010, the spring was warm, very wet and highly variable, with extremely high precipitations in May. The average temperature in March was 2.1 °C; April and May were characterized by higher temperatures than the average 1966-2005 multi-year data (Table 2). However, the average temperature in May was similar to the multi-year mean: 12.0 and 12.5 °C, respectively. The subsequent months of the 2010 growing season, i.e. June, July and August, were characterized by the temperatures higher by 0.7, 3.6 and 2.1 °C than the multi-year average temperatures for the same months. With respect to precipitations, the wet March in 2010 (36.7 mm) was followed by dry April, with a 50% precipitation deficit in comparison with the multi-year data for this month (Table 1). The rainfall in May was extremely high and June and July were slightly wetter than the forty-year averages. In August, rainfall was distinctly higher (by 39.5%, i.e. 27 mm) in relation to the precipitation recorded for 1966-2005.

In 2011, the second year of the experiment, all the months of the growing season, i.e. from April to August, were slightly warmer than the multi-year statistics. The precipitations during those months were 51% to 42% lower than the long-term average precipitations (Table 2). The deficit of water in spring months was probably partly compensated by heavy rainfalls in July (202.8 mm). August was also wet, with the total precipitation of 82.1 mm.

Weeding and assessment of the health of crops

The observations of the plantations completed at the tillering phase in both years of the trials showed that wheat and spelt fields grown according to the organic farming recommendations were not infested with weeds (data not shown). This was both the residual impact of the preceding crop, potato, which left the field stands with very few weeds and the effect of the conventional soil tillage, which regulated weeds. In all the trials, spelt was less infested with weeds than common wheat, which proves that the examined spelt varieties could compete successfully with weeds for sunlight, water, living space and nutrients. The weeds recorded before wheat harvest, irrespective of the sowing date, were *Setaria viridis, Convolvulus arvensis, Erodium cicutarium, Chenopodium album*. Among the identified unwanted plants, the most numerous one on all wheat fields was *Setaria viridis*. This taxon grows on a mass scale on more fertile soils and infests all kinds of sown crops, but develops best on fields cropped with tuber plants and cereals. The counts of *Setaria viridis* plants ranged from 155 on plots sown with cv. Trappe (2nd sowing date) to 65 individuals per 1m^2 on plots with the spelt cv. Speltz aus Tzaribrod (2nd sowing date).

During the growing season, the following pathogens appeared on leaves and ears of common and spelt wheat plants: *Puccinia striiformis*, *Puccinia recondita*, *Septoria tritici*, *Stagonospora nodorum Fusarium* spp. The stem base was attacked by *Fusarium* spp. and *Oculimacula yallundae* (Figure 1, Table 2).

Higher incidence of diseases during the growth and development of the analyzed varieties of common and spelt wheat was closely related to the genotype of a plant and the course of the weather conditions. The year 2010 was dry, hence the diseases did not spread so intensively as in 2011 (Figure 1). In general, our examinations demonstrated that the spelt varieties were less infested by *Puccinia recondita*, *Septoria tritici*, *Puccinia stiriformis* as well as in 2011 also *Fusarium* spp. on ears than the cultivars of common wheat. Among leaf diseases, the dominant ones were *Puccinia recondita* and *Septoria tritici.* Each year, the following diseases were observed: septoria leaf spot, yellow rust and brown rust of wheat. In 2010, *Septoria tritici* infected common and spelt wheat to the same degree, but in 2011 spelt was less affected than common wheat. These results correspond to some earlier findings reported by Cyrkler-Degulis and Bulińska-Radomska (2006), who demonstrated low vulnerability of spelt wheat to pathogenic infestation.

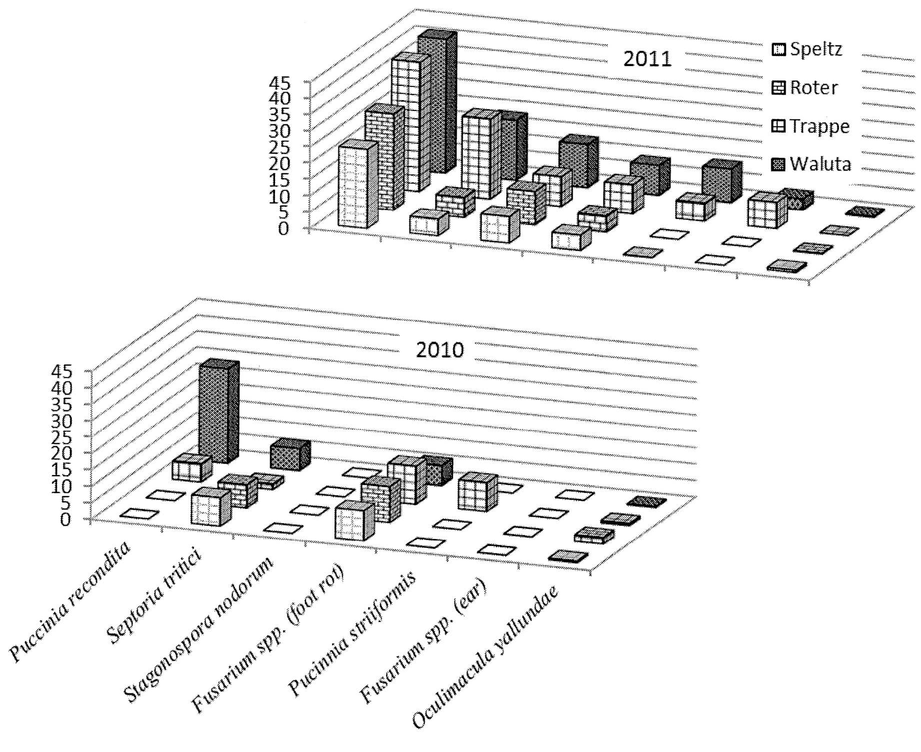

Figure 1. Disease infestation of common and spelta wheat species in 2010 and 2011.

The wheat varieties sown on the optimal date (1st date of sowing) were more strongly infected by *Septoria tritici* than the ones sown two weeks later, which proves that the developmental cycle of wheat from the 1st date of sowing coincided with the development of the pathogen (Table 3).

Table 3. The infection of *T. aestivum* (cvs. Waluta and Trappe) and *T. spelta* (cvs. Roter and Speltz) plants by fungal pathogens (*interaction cultivars × sowing time*) in the years of study (2010 and 2011)-leaf and spike area (%).

Species	Year	Waluta				Trappe				Roter				Speltz			
		ST-I		ST-II		ST-I		ST-II		ST-I		ST-II		ST-I		ST-II	
Septoria tritici	2010	7.5	abc	6.0	bc	2.5	d	1.0	e	9.5	ab	4.5	c	11.0	a	6.5	bc
	2011	19.8	b	17.0	b	31.3	a	14.3	b	9.3	c	3.0	d	7.5	c	2.8	d
Puccinia recondita	2010	32.5	a	25.0	a	5.0	b	6.0	b	-		-		-		-	
	2011	38.8	b	43.8	ab	30.5	c	49.0	a	39.5	b	19.3	d	30.0	c	18.3	d
Pucinnia striiformis	2010	-		-		5	b	12.5	a	-		-		-		-	
	2011	8.8	b	11.5	a	2.0	c	9.0	b	-		-		0.3	d	-	
Stagonospora nodorum	2010	-		-		-		-		-		-		-		-	
	2011	7.8	c	18.8	a	6.3	c	11.7	b	11.8	b	8.5	c	9.0	c	7.3	c
Fusarium spp. (head blight)	2010	-		-		-		-		-		-		-		-	
	2011	0.5	d	6.3	b	1.8	c	14.3	a	-		-		-		-	
Fusarium spp. (foot rot)	2010	8.0	b	4.0	c	13.0	a	10.0	ab	11.5	ab	10.5	ab	13.5	a	5.0	c
	2011	8.5	a	9.5	a	8.5	a	9.0	a	4.5	b	5.5	b	4.0	b	5.5	b
Oculimacula yallundae	2010	0.5a		-		1.5a		-		2.5a		1.5a		0.5a		0.5a	
	2011	0.5b		-		-		-		-		0.5b		1.5a		-	

ST-I - optimum sowing time, ST-II - sowing time delayed by 14 days.
“-“ - not recorded.
a, b, c, … homogenous groups horizontally, acc. to SNK multiple range test.

The wheat cultivar Waluta appeared to be particularly sensitive to the infection by *Puccinia rekondita*. In a study by Stalenga and Jończyk (2008), *Pucinia recondita* was the most important pathogen, especially prevalent under very unfavorable weather conditions, in a dry year. The cultivar Trappe sown on the optimal date was less infected by the pathogen. On the other hand, spelt cultivars had a lower infection index when sown two weeks later. A more intensive occurrence of *Septoria tritici* was demonstrated on leaves of common wheat than spelt. The assessment of the health status of wheat plants on the plantation revealed sporadic cases of the infestation of the common wheat variety Trappe with *Pucinnia striiformis* in the first year. In turn, this pathogen was detected on both wheat cultivars, Trappe and Waluta, especially after the delayed sowing (2nd date), which - as reported in our previous experiment (Chan, 2005) - is associated with the development of this disease. *Puccinia striiformis* occurred on common wheat in 2011. No symptoms of this pathogen were found on spelt wheat during its vegetative growth. The infection of *T. aestivum* and *T. spelta* with *Stragonospora nodorum* in the second year of the vegetation may imply that this fungal pathogen was able to overcome the sensitivity to the weather conditions prevalent on the field. *Stragonospora nodorum* appeared only in the second year. The index of spelt spike infestation with *Stagonospora nodorum* was 20% higher than determined for common wheat. Spikes of the variety Roter Sommerkolben were particularly badly infected, The date of sowing had a significant effect on the intensity of the pathogenic symptoms in common wheat. Both cultivars of common wheat were less badly infected by *Stagonospora nodorum* when sown on the optimal rather than postponed date. The cultivar Waluta was much more sensitive to infections than cv. Trappe. Our results support the conclusions drawn by Cyrkler-Degulis and Bulińska-Radomska (2006), who claimed that spelt wheat had low sensitivity to pathogenic infections. However, the second year of our experiment suggests that the resistance of spring spelt to brown rust and yellow rust of wheat can be overcome by *P. recondita* and *P. striiformis*. As the research completed by Kema and Lange (1992) showed, spelt is resistant to *Puccinia striiformis* Westend. f. sp. *tritici*. Stechno et al. (2010) on the basis of their study on wheat species from the Czech collection of wheat genetic resources showed that the resistance to powdery mildew field infection strongly depended on differences among weather conditions in particular years. Our results also indicate that the weather conditions are more important than the date of sowing for the health of spelt wheat.

Fusarium fungi occurred less intensively than *Stagonospora nodorum* and only on spikes of common wheat. Delayed sowing reduced the incidence of this pathogen. The cultivar Trappe was more vulnerable to fusarial infections. *Oculimacula yallundae* infected spelt, especially cv. Roter Sommerkolben, much more often than common wheat. Postponing the sowing date resulted in a considerable reduction or complete eradication of the symptoms of the disease. As demonstrated by Suchowilska et al. (2009), loose spikes of spelt wheat, placed high above the flag leaf, maintain a low level of humidity, which enhances the health of spikes. It also depresses, particularly in rainy years, the risk of infection caused by fungal pathogens, mainly *Fusarium* spp., which produce toxic metabolites. Moreover, our studies on the isolation of fungal species from the stem base verified the results reported by Cook (1980), who claimed that *Fusarium* spp. fungi have a higher contribution as causal agents to cereal infections.

Content of chlorophyll

Diagnosing the nitrogen nutritional status of plants and using the diagnostic results to determine optimum rates of this nutrient are extremely important in organic and precision farming (Grove and Navarro, 2013; Haboudane et al., 2002; Peltonen et al., 1995). Our studies showed that the content of chlorophyll (SPAD) generally decreased in the subsequent developmental phases GS 17, GS 25 and GS 35 and was varied between the wheat species, common and spelt wheat, as well as between the years: 2010 and 2011 (Figure 2.). Irrespective of the wheat species, higher SPAD values were recorded in 2011, when the weather conditions during the plant growing season allowed higher accumulation of chlorophyll than in 2010. Under the climatic conditions of 2011, the genetic potential of common wheat let the plants use more efficiently the soil nitrogen supply and accumulate more chlorophyll. In turn, under the highly changeable weather in the vegetative season of 2010, higher SPAD readings were obtained for spelt than for common wheat, although they were on the level of SPAD values achieved in 2011. The results found for spelt confirm its stable content of chlorophyll over the years and higher tolerance to variable weather conditions. A similar dependence has been observed for spring barley (Zuk-Golaszewska, 2008). The content of chlorophyll in spring barley leaves was higher, on the level of 42.0 SPAD, even when the weather was changeable.

The analysis of SPAD tests performed on both wheat species sown on two different dates revealed convergent results in 2010 and slightly different ones in 20101, when the distribution of SPAD values in the subsequent phases of plant development was similar in the case of plants sown on the 2nd date.

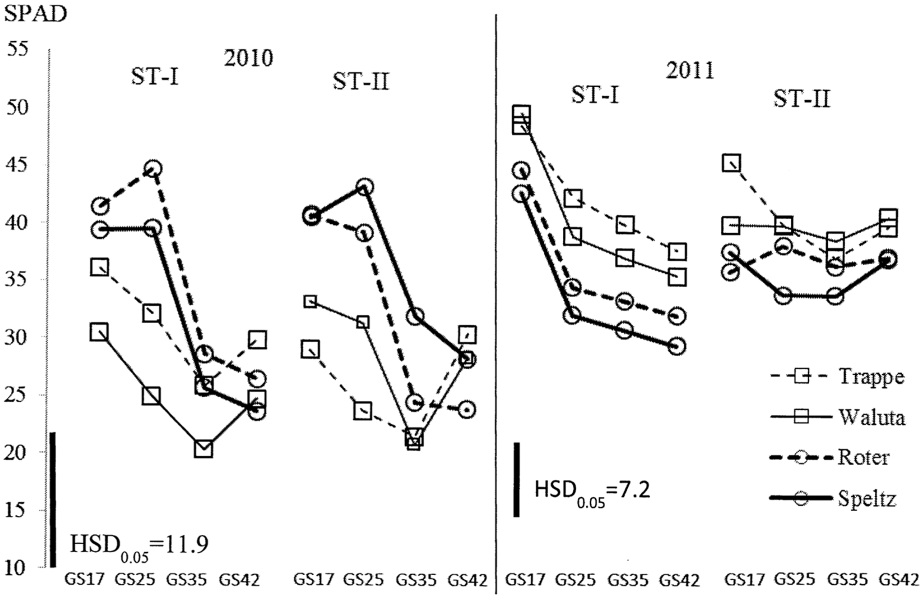

Figure 2. Changes in content of chlorophyll in common wheat and spelt wheat varieties recorded in development phases in plants sown on different dates (ST-I - optimal sowing date and ST-II - sowing date delayed by 14 days) and in two years (2010, 2011). HSD is the Honest Significant Difference acc. to Tukey's T test calculated for phases nested in cultivars and sowing dates in the years.

The experiment presented in this paper demonstrated that the content of chlorophyll is correlated with the level of yields. Figure 3 shows the relationship between grain yields and the content of SPAD-measured chlorophyll during the subsequent plant development phases GS17, GS25, GS35 and GS41. The prognostic value of the defined linear models increased when the SPAD reading was performed on a later development stage, whereas the SPAD reading itself was more strongly correlated with the grain yield of common wheat than spelt. The adjustment of the linear models to empirical data regarding common wheat was high and - measured with the value of the determination coefficient in the four subsequent SPAD readings - equalled 0.63, 0.77, 0.93 and 0.95. At the same time, the regression coefficient values obtained in the same development phases show that on average each SPAD unit corresponded to an increase in grain yield of 78.8, 97.4, 86.5 and 133.0 kg ha^{-1} respectively. In respect of spelt wheat, significant relationships between SPAD readings and grain yield were noticed up to phase GS35. The determination coefficient of the linear model fit in phase GS35 was 0.40 and in phase GS41 - 0.62. An increase in the content of chlorophyll by a SPAD unit in phases GS35 and GS41 resulted in an increase in grain yield by 61.4 and 59.6 kg ha^{-1}, respectively.

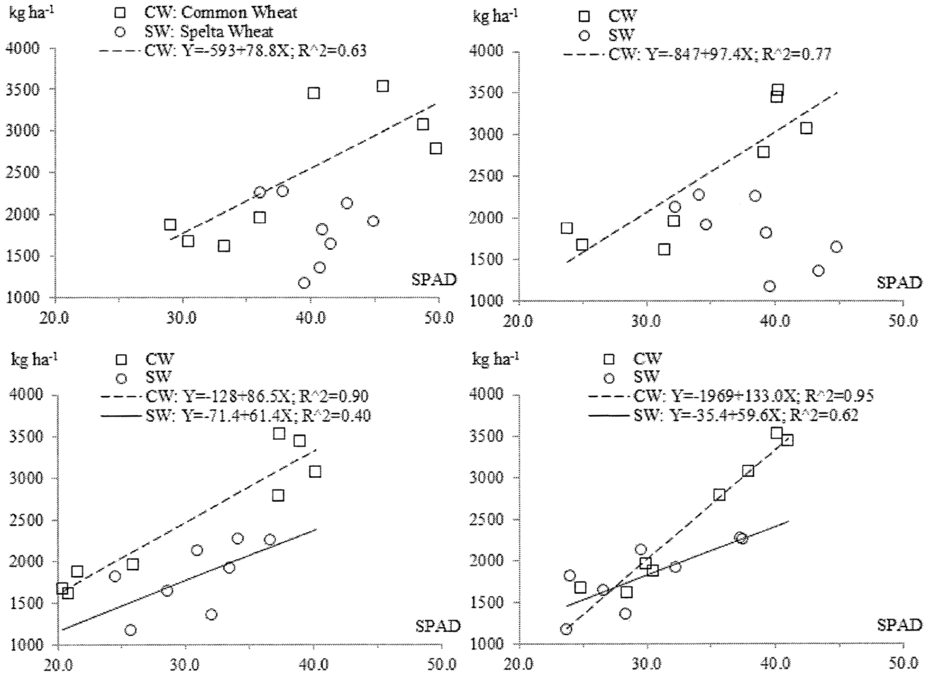

Figure 3. Relationship between SPAD measured in GS 17 (upper left), GS 25 (upper right), GS 35 (down left) and GS 41 and yield.

Simple linear models determined for the relationships between the content of chlorophyll and grain yield can be taken into consideration when forecasting yields of common wheat, but analogous prognosis for spelt wheat should originate from a model established in later development phases, starting from phase GS 35.

Morphological traits and yield components

Table 4 sets means of morphological traits and yield components determined for the wheat species in the two years and on two sowing dates. Significant differences across all the analyzed traits were noted only for cultivars and for the interactions *cultivar × year*. Spelt plants were taller and had longer spikes, although the other yield components attained lower values than in the case of common wheat, which was also confirmed by a report of Pospisil et al. (2011) on the winter cultivar Ostro.

Table 4. Means for morphological traits and yield components of wheat cultivars in sowing terms and years of study.

Cultivars (V)	Year of Study				Year of Study		Sowing Time (ST)		Cultivars
	2010		2011						
	Sowing Time				2010	2011	ST-I	ST-II	
	ST-I	ST-II	ST-I	ST-II					
Length of stem (cm)									
Trappe	64.3	66.1	59.0	64.7	65.2	61.8	61.7	65.4	63.5
Waluta	72.5	77.9	71.4	72.5	75.2	72.0	72.0	75.2	73.6
Roter	84.4	74.9	77.2	84.5	79.7	80.9	80.8	79.7	80.3
Speltz	80.2	61.3	87.6	88.4	70.8	88.0	83.9	74.8	79.4
HSD$_{0.05}$	ns				5.9		ns		3.5
Means	75.4	70.1	73.8	77.5	72.7	75.7	74.6	73.8	
HSD$_{0.05}$	7.4				ns		ns		
Length of spike (cm)									
Trappe	6.50	6.83	5.77	5.44	6.66	5.60	6.14	6.13	6.13
Waluta	6.28	5.98	6.28	6.49	6.13	6.39	6.28	6.24	6.26
Roter	8.64	7.39	6.36	6.67	8.01	6.52	7.50	7.03	7.26
Speltz	7.28	6.38	6.00	6.32	6.83	6.16	6.64	6.35	6.49
HSD$_{0.05}$	0.61				0.90		ns		0.53
Means	7.17	6.64	6.10	6.23	6.91	6.17	6.64	6.44	
HSD$_{0.05}$	0.42				ns		ns		
Number of kernels per spike									
Trappe	36.7	33.6	24.4	24.3	35.2	24.4	30.6	29.0	29.8
Waluta	21.6	29.9	25.5	26.2	25.7	25.8	23.5	28.0	25.8
Roter	22.0	16.6	12.4	12.0	19.3	12.2	17.2	14.3	15.7
Speltz	16.6	15.9	12.7	11.3	16.3	12.0	14.7	13.6	14.1
HSD$_{0.05}$	ns				ns		ns		4.16
Means	24.2	24.0	18.8	18.5	24.1	18.6	21.5	21.2	
HSD$_{0.05}$	ns				ns		ns		

Continue Table 4.

Cultivars (V)	Year of Study				Year of Study		Sowing Time (ST)		Cultivars
	2010		2011						
	Sowing Time								
	ST-I	ST-II	ST-I	ST-II	2010	2011	ST-I	ST-II	
Weight of kernels per spike (g)									
Trappe	0.91	0.84	1.00	0.88	0.88	0.94	0.96	0.86	0.91
Waluta	0.84	0.84	1.24	1.18	0.84	1.21	1.04	1.01	1.02
Roter	0.70	0.48	0.52	0.50	0.59	0.51	0.61	0.49	0.55
Speltz	0.45	0.36	0.44	0.37	0.40	0.41	0.45	0.36	0.40
$HSD_{0.05}$	ns				0.21		ns		0.12
Means	0.73	0.63	0.80	0.73	0.68	0.77	0.76	0.68	
$HSD_{0.05}$	ns				ns		0.05		
Weight of thousand kernels (g)									
Trappe	65.7	46.9	36.9	33.2	56.3	35.0	51.3	40.0	45.6
Waluta	53.6	51.7	42.7	40.4	52.6	41.6	48.1	46.1	47.1
Roter	32.3	28.7	42.9	39.4	30.5	41.2	37.6	34.1	35.8
Speltz	27.1	24.4	37.2	36.5	25.7	36.9	32.1	30.4	31.3
$HSD_{0.05}$	ns				14.9		ns		8.7
Means	44.6	37.9	39.9	37.4	41.3	38.7	42.3	37.7	
$HSD_{0.05}$	ns				ns		ns		

The length of spikes was similar in both spelt varieties Roter and Spelz (80.3 cm and 79.4 cm, respectively) and spelt plants were on average taller than common wheat plants (10% taller than cv. Waluta and 26% than cv. Trappe). The longest spike was produced by cv. Roter spelt plants: 7.26 cm, which was 15% longer than spikes of the other varieties. The yield components in cultivars of the same species were only slightly varied, but the differences between the wheat species were very large. The spelt varieties, despite having long spikes, produced 45-52% fewer kernels, with the 49-60% lower weight of kernels per spike and 22-34% lower one thousand kernels weight than the common wheat cultivars. When analyzing the variation of cultivar-specific traits in the two years of the experiment, a specific response of cultivars was more distinguishable than the inter-species variation. In 2010, taller spelt plants of the cv. Roter (78.7 cm) grew longer spikes (8.01 cm) than cv. Speltz plants (70.8 cm and 6.83 cm, respectively for the traits). However, in 2011, the cultivar Speltz grew taller, but the length of spikes was similar in both spelt varieties. As a result, the cultivar Roter presented better values of the yield component out of the two spelt varieties. The height of common wheat plants was comparable in both years. However, cv. Trapper grew longer spikes in 2010, while achieving a similar weight of kernels per spike, which meant a higher weight of 1,000 kernels than in 2011. A study by Kovalina et al. (2010) conducted to compare agronomic parameters of einkorn, emmer, spelt and intermediate bread wheat grown in organic farming demonstrated that spelt wheat had long and lax spikes.

Among the other analyzed factor and interaction effects, significant ones were the date of sowing on weight of kernels per spike and the interaction *year of study × date of sowing* on the length of spike. These results suggest that it might be possible to achieve a larger mass of kernels per spike on the optimal date of sowing or to obtain longer spikes on the optimal sowing date under the weather conditions which occurred in 2010 or else a similar length of spikes irrespective of the sowing date under the conditions recorded in 2011.

Table 5 presents values of path coefficients illustrating the direct and indirect effect of morphological traits and grain yield components (stem length, spike length, number of kernels per spike, weight of kernels per ear, 1,000 kernels weight) on spelt wheat and common wheat grain yields. The determined multiple regression models for both wheats were statistically significant. The determination coefficient for the model of regression of variables in spelt was R^2=0.47 and in wheat R^2=0.56, which means that a large share of the grain yield variability remains unexplained.

Table 5. Direct and indirect path coefficients in determination of grain yield of spelt and common wheats.

Variables/traits	Path coefficients (direct effects on diagonal)					Correlation coefficient with yield
	X_1	X_2	X_3	X_4	X_5	
Spelta wheat						
X_1 - Length of stem	0.343	0.013	-0.021	-0.111	0.328	0.551*
X_2 - Length of spike	0.011	0.420	0.110	-0.485	-0.218	-0.162
X_3 - No of kernels per spike	-0.057	0.369	0.125	-0.415	-0.355	-0.334
X_4 -Weight of kernels per ear	0.064	0.342	0.087	-0.596	0.136	0.034
X_5 - Weight of thousand kernels	0.156	-0.127	-0.062	-0.113	0.721	0.576*
Random factor: 0.311						
Common wheat						
X_1 - Length of stem	-0.007	-0.173	-0.056	0.342	-0.147	-0.042
X_2 - Length of spike	-0.002	-0.531*	-0.207	0.587	0.025	-0.128
X_3 - No of kernels per spike	-0.001	-0.311	-0.353	0.587	0.111	0.034
X_4 -Weight of kernels per ear	-0.002	-0.258	-0.172	1.207*	-0.218	0.557*
X_5 - Weight of thousand kernels	-0.003	0.034	0.101	0.674	-0.391	0.415*
Random factor: 0.248						

* Significance at P≤0.05.

The spelt grain yield was significantly correlated with the length of spike (r_{X1}=0.551) and weight of 1,000 kernels (r_{X5}=0.576). The estimated direct effect of the length of spike was smaller (p_{X1}=0.343) than the simple correlation coefficient and compensated by the positive effect of the 1,000 kernels weight (p_{X5}=0.328). On the other hand, the estimated indirect effect of the one thousand kernels weight (p_{X1}=0.721) was higher than the estimated value of the correlation coefficient, which was a result of the negative indirect effect of the length of spike and number of kernels in a spike. Our analysis of the dependences observed for spelt grain yields revealed relatively strong direct effects of all the considered independent variables, which may suggest the relatively equal value of morphological traits and brain yield components in an assessment of the productivity of spelt grown in the organic farming system.

In the assessment of the relationships of common wheat grain yield, the correlations between grain yield versus yield components such as number of kernels per spike and weight of a thousand kernels proved to be significant. Both variables demonstrated high direct and indirect effects, possibly suggesting that the productivity of this plant in organic agriculture is determined by direct yield components, above all the weight of kernels per spike and 1,000 kernels weight associated with robust grains.

Yield and harvest index

While comparing yields of the spelt and common wheat cultivars, it was found out that the yields produced by the same wheat species were similar, with the spelt varieties producing yields comparable to those by cv. Waluta (2382 kg ha^{-1}) but significantly lower than cv. Trappe (2607 kg/ha), that is 27% and 34% less by cv. Roter and Speltz, respectively (Table 6).

The significant effect of the year × cultivar interaction appeared because the cultivars produced different yields in the two years of the investigations. Under the relatively unfavourable external conditions in 2010, the spelt and common wheat cultivars generated similar yields, but in 2011, when the weather was better, spelt yields remained on the same level as in the previous year whereas the common wheat cultivars Trappe and Waluta yielded much better (42% and 47% higher yields, respectively). At the same time, in 2011 spelt yields were significantly lower than yield produced by the common wheat cv. Trappe. For all the wheat cultivars, delayed sowing meant higher yields, but the effect was non-significant in 2010 and significant (16% higher yield) in 2011 (the year × date of sowing interaction). Thus, it can be assumed that under unfavourable weather conditions around the sowing and emergence of plants, postponing the date of sowing can lead to increased grain yields.

Table 6. Means for yield of grains and straw and harvest index of wheat cultivars in sowing terms and years of study.

Cultivars (V)	Year of Study				Year of Study		Sowing Time		Cultivars
	2010		2011						
	Sowing Time				2010	2011	ST-I	ST-II	
	ST-I	ST-II	ST-I	ST-II					
Hulled grain yield (kg ha^{-1})									
Trappe	1952	1866	3075	3535	1909	3305	2513	2229	2607
Waluta	1667	1615	2791	3455	1641	3123	1772	1646	2382
Roter	1636	1811	1908	2262	1723	2085	2701	2535	1904
Speltz	1168	1362	2124	2270	1265	2197	2036	1816	1731
$HSD_{0.05}$	ns				1131		ns		664
Mean	1606	1664	2475	2880	1635	2677	2040	2272	
$HSD_{0.05}$	456				ns		241		
Straw yield (kg ha^{-1})									
Trappe	2326	2051	2540	2834	2189	2687	2433	2060	2438
Waluta	2088	2463	2032	2995	2275	2513	2430	2862	2394
Roter	2134	2350	2727	3182	2242	2955	2443	2729	2598
Speltz	2142	2612	3583	3422	2377	3503	2766	3017	2940
$HSD_{0.05}$	ns				ns		ns		597
Mean	2172	2369	2721	3108	2271	2914	2447	2739	
$HSD_{0.05}$	ns				633		369		
Harvest Index (%)									
Trappe	46.2	47.5	54.6	55.3	46.8	55.0	50.4	50.7	50.9
Waluta	44.2	38.8	57.3	53.2	41.5	55.2	41.9	38.0	48.4
Roter	42.4	43.3	41.3	41.7	42.9	41.5	51.4	46.0	42.2
Speltz	38.5	34.3	37.5	39.8	36.4	38.7	42.5	37.1	37.5
$HSD_{0.05}$	ns				15.0		ns		8.8
Mean	42.8	41.0	47.7	47.5	41.9	47.6	45.3	44.2	
$HSD_{0.05}$	ns				ns		ns		

Analogously to grain yield, straw yield was typical of the analyzed species of wheat. The highest straw yield was produced by the spelt variety Speltz 2940 kg ha^{-1}, 20-23%. Higher than straw yields of common wheat. In general, mean straw yields of all the examined cultivars were 28% higher in 2011 and 12% higher at the delayed sowing.

The assessment of the harvest index to a large extent coincides with the evaluation of grain and straw yields. Overall, the harvest index of the grown wheats was low. It reached 50.9% for cv. Trappe, which was quite similar to the harvest index calculated for cv. Waluta (48.4%) but significantly higher than for spelt cultivars Roter (42.2%) and Speltz (37.5%). Similar values were reported by Konvalina et al. (2010). The harvest index was 48% for bread wheat and 38% for spelt wheat.

The *year* × *cultivar* interaction effect was conditioned by the variation of the harvest index between the years - similar values of the index for all the cultivars were obtained in 2010, but in 2011 the harvest index of cv. Trappe, producing the highest yield in the experiment, was significantly higher than the harvest index for the spelt variety Speltz, which produced the lowest grain yield but the highest amount of straw.

Nutritional value

Nutritional quality of wheats is attributed to the content of macro- and micronutrients in grains. The high nutritional quality of spelt makes it a good choice in rational and special diets (Lacko-Bartosoca and Redlova, 2007). Spring wheat cultivars: hulled *Triticum aestivum* (Trappe and Waluta) and non-hulled spring *Triticum spelta* (Roter Sommerkolben and Speltz aus Tzaribrod) were differentiated significantly in the content of total ash, nitrogen and micronutrients: copper, iron and zinc (Table 7). The common wheat cultivars have the same content of all nutrients, in general lower than the spelt cultivars. In comparison with the average content of the analyzed ingredients in common wheat, the spelt cultivars Roter and Speltz had a significantly higher amount of total ash (44-86% higher), nitrogen (18-24%), copper (33-56%), iron (18-31%) and zinc (4-27%).

Table 7. The content of ash (%) and macro- and micronutrients in the grains of wheat.

Specification	Cultivars				$HSD_{0.05}$
	Trappe	Waluta	Roter	Speltz	
Total ash (% of ODM)	2.40	2.16	4.25	3.29	0.90
	Macronutrients (% of ODM)				
N	1.88	2.02	2.42	2.31	0.28
P	0.337	0.303	0.407	0.410	ns
K	0.540	0.430	0.547	0.520	ns
Mg	0.140	0.130	0.147	0.143	ns
Ca	0.030	0.030	0.043	0.037	ns
Na	0.0030	0.0037	0.0033	0.0030	ns
	Micronutrients (mg kg^{-1} of ODM)				
Cu	3.40	3.19	5.15	4.37	0.75
Fe	38.7	40.1	46.8	44.7	7.22
Mn	46.7	41.4	57.7	51.8	ns
Zn	35.2	34.8	44.4	36.2	7.31

Summary and Conclusions

Growing spelt and common wheat according to the rules of organic agriculture helps to keep the weed infestation of fields to the minimum. The degree of infection of wheat plants with diseases depends less on postponed sowing than on the genotype and weather conditions during the plant growing season. Cultivars of *Triticum spelta* are more tolerant to unfavourable environmental conditions than cultivars of *Triticum aestivum*, showing (i) better adaptability to habitat conditions, when - due to the worse weather - the uptake of nutrients from soil can be limited, (ii) stronger competitiveness against weeds and (iii) higher tolerance to diseases of leaves and stems.

The content of chlorophyll in spelt wheat and common wheat measured by the SPAD value is correlated with the productivity of a whole plantation, and in our experiment the SPAD reading was more strongly correlated with the yield of common wheat than that of spelt, irrespective of the date of sowing. The prognostic value of the determined models is better when SPAD readings are made on a later plant development phase, which is why SPAD measurements made at phase GS35 or GS41 are recommended.

The analysis of the relationships between spelt grain yield and morphological traits or yield components demonstrated characteristic, relatively big direct effects of all the traits, which may imply relative equivalence of spelt's morphological traits and grain yield components in the evaluation of the productivity of spelt plants grown in organic agriculture. In turn, the productivity of common wheat in organic farming is shaped by the direct yield components connected with the robustness of kernels - weight of kernels per spike and weight of a thousand kernels.

The spelt cultivars Roter and Speltz as well as the common wheat cultivars Trappe and Waluta show similar yielding within the species, but the spelt species can produce yields comparable to wheat cultivars (e.g. cv. Waluta) or significantly lower (27-34% less than cv. Trappe). In analogous environmental conditions on organic fields, spelt cultivars produce stable yields. Under unfavourable weather conditions during the vegetative season, spelt wheat can give yields which compare to yields of common wheat, but when the weather is relatively better, common wheat varieties generate yields higher by 42% (cv. Trappe) up to 47% (cv. Waluta). Under worse weather conditions during the sowing and emergence of wheat plants, delayed sowing may result in an increase in the yield of grain or straw. The highest straw yields were produced by the spelt variety Speltz (2940 kg/ha), 20-23% higher than straw yields obtained from common wheat. Depending on the growing conditions, straw yields can range within 28%, but when sown on a two-week later date, the differences in straw yield are about 12%.

The common wheat cultivars have the same spectrum of the nutrients, but generally lower than in spelt cultivars. In comparison with the average content of analyzed properties in common wheat the spelt cultivars Roter and Speltz had significantly higher amount of total ash by 44-86%, nitrogen by 18-24%, copper by 33-56%, iron by 18-31% and zinc by 4-27%, respectively.

The spelt cv. Roter Sommerkolben, which is not free threshing, had the most desirable content of nutrients and the highest nutritional value.

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